Power System Dynamic Performance with STATCOM Controller

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Abstract- The Static Compensator (STATCOM), earlier known as Static Condenser (STATCON), is one of the new generation Flexible AC transmission Systems (FACTS) devices with a promising future of applications in power systems. The static synchronous compensators employing gate turn-off thyristors integrate the technique of static var compensators and voltage source converters. Reactive current and voltage control at midpoint of a long transmission line using STATCOM is presented in this paper. The STATCOM is modeled as a reactive current source with a time delay. The effectiveness of speed and feedback control loops in providing damping was investigated for the linearized model. Proportional, integral, derivative controllers and their combinations were tried in both the speed and the voltage loops. By increasing the gain in the speed feedback loop, an arbitrary amount of damping can be achieved at the cost of large excursion of controller output current and system voltage levels. A suitable response has been achieved by using proportional control in the voltage loop and proportional-derivative control in the speed feedback loop.

Keywords: FACTS, STATCOM, Damping Control.

I. Introduction:

It is a well-established practice to use reactive power compensation to increase power transmission in AC power systems. Fixed or mechanically switched capacitors and reactors have long been employed to increase the steady-state power transmission by controlling the voltage profile along the lines. [1]

The concept of Flexible AC transmission Systems (FACTS) envisages the use of solid-state controllers to achieve flexibility of system operation with fast and reliable control [1,2]. Fast control of reactive power can allow secure loading of transmission lines nearer their thermal limits, greater control over the power flow, regulate voltage and improve system damping. The Static synchronous compensator (STATCOM) is a second-generation FACTS device that integrates the technique of static var compensator and voltage source converter and provides a new concept of reactive power control [2-4]. STATCOM is an active device, which can inject both real and reactive power to the system in a very short time and therefore has the ability to improve the damping and voltage profiles of the system. It is reported that STATCOM can offer a number of performance advantages for reactive power control applications over the conventional SVC because of its greater reactive current output at depressed voltage, faster response, better control stability, lower harmonics and smaller size, etc.

The dynamic modeling of power system installed with STATCOM and its controls are discussed in [2-5]. The linearized 5th order Phillip-Heffron model is presented in reference [4] for single machine infinite-bus power system A more simplified and lower order dynamic model is given in [3] in which STATCOM is modeled as a controllable current source with time delay. The application of STATCOM for the reactive power compensation of a long transmission line by regulating the voltage at its midpoint is given in [2]. The design of voltage controller and the analysis of its dynamic behavior using eigenvalue analysis and digital simulation are presented in that article.

In this paper a single machine infinite-bus system with a long transmission network with STATCOM installed at its mid point has been simulated. The effectiveness of the speed and voltage control loops was analyzed by considering the linearized model. Results show that the voltage control loop alone does not give any effective control while the speed loop has effective control over the electromechanical as well as electrical transients. It was observed that a PD control in the speed loop is most effective for damping control.

II. Single Machine Infinite Bus model with STATCOM

A single machine infinite bus (SMIB) power system installed with the STATCOM at the middle of the transmission line is shown in Fig.1. Its equivalent circuit is shown in Fig. 2. The following assumptions are made [3].

1. The details of the exciter and turbine control loops are not considered. The generator is modeled by the transient emf in the quadrature axis, Eq', and the mechanical power input, P_m is considered to remain constant.

2. Modeling of STATCOM as a controllable reactive current source with time delay. The V-I characteristic is shown in Fig.3. Inductive current generated by STATCOM is considered positive.

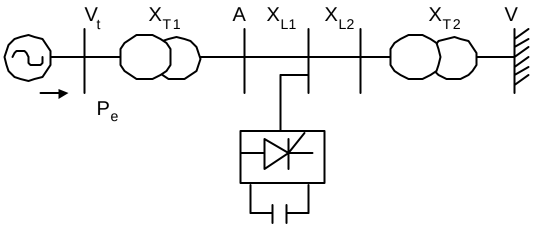

Figure1. A single machine infinite bus system with STATCOM.

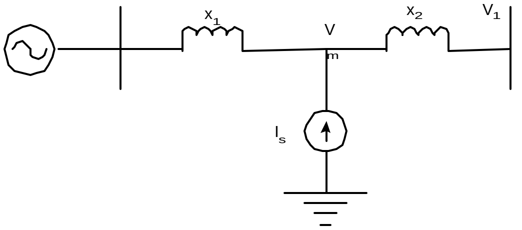

Figure2. Equivalent circuit of Fig. 1.

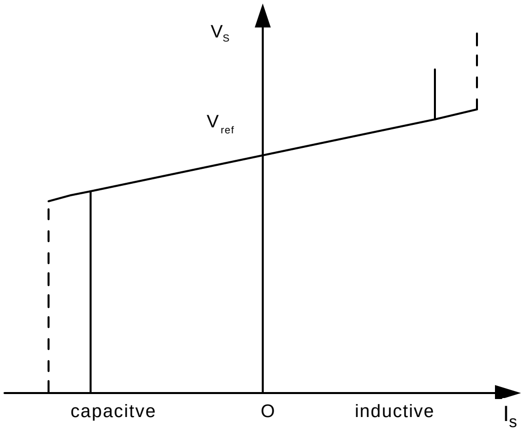

Figure 3. V-I characteristic of STATCOM

The SMIB system with the STATCOM can be described by the following dynamic model [3]

$$\begin{aligned} \Delta\dot{\delta} &= \omega_o \Delta\omega \\ \Delta\dot{\omega} &= -\frac{D}{2H}\Delta\omega - \frac{1}{2H}\Delta P_e \\ \Delta\dot{I}_s &= \frac{1}{T}\left(-\Delta I_s + K\Delta u\right) \end{aligned} \qquad (1)$$

where,

$$P_e = \frac{E_q' V_m}{x_d' + x_1}\sin\theta + \frac{V_m^2}{2}\frac{x_d' - x_q}{(x_d' + x_1)(x_q + x_1)}\sin 2\theta \qquad (2)$$

The components of mid-section voltage V_m are expressed as

$$V_{mq} = \frac{(x_1 + x_d')V\cos\delta + E_q' x_2 + I_s x_2 \cos\theta (x_1 + x_d')}{(x_1 + x_2 + x_d')} \qquad (3)$$

$$V_{md} = \frac{(x_1 + x_q)V\sin\delta + I_s x_2 \sin\theta (x_1 + x_q)}{(x_1 + x_2 + x_q)} \qquad (4)$$

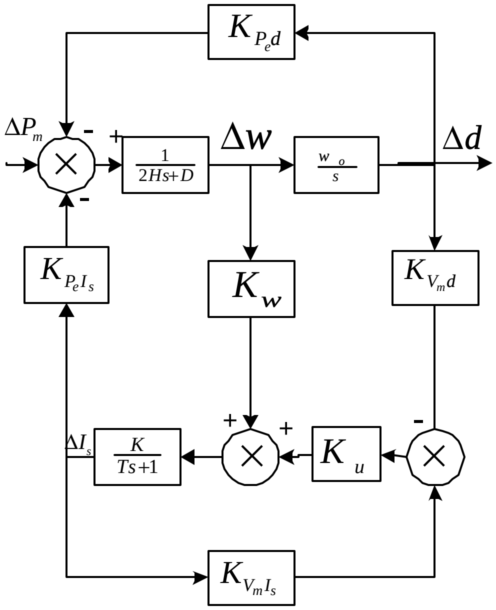

Figure 4. Block diagram of linearized system.

In the above, δ is the load angle in radian, ω is relative speed, 2H is the inertia constant in seconds, D is the damping constant, P_e is the delivered electrical power, I_s, u, K, and T are the output current, controller output, gain and time constant of the STATCOM, respectively. X_d' and X_q are the direct axis transient reactance and quadrature reactance of the generator, respectively. X_1 and X_2 are the sum of reactance of transformer and transmission line as shown in Fig.3. θ is the phase difference between quadrature axis of the generator and V_m and expressed as $\tan\theta = V_{md}/V_{mq}$. By linearizing equations (2)-(4), around the equilibilrium point, we obtain

$$\Delta P_e = K_{P_m d}\Delta\delta + K_{PI_s}\Delta I_s \qquad (5)$$

$$\Delta Vm = K_{V_m d}\Delta\delta + K_{V_m I_s}\Delta I_s \qquad (6)$$

where,

$$K_{V_m d} = \partial V_m / \partial\delta \ , \qquad K_{V_m I_s} = \partial V_m / \partial I_s$$

$$K_{P_e d} = \partial P_e / \partial d \ , \qquad K_{P_m I_s} = \partial P_e / \partial I_s$$

The linearized power system model is shown in Fig.4. The output of the STATCOM controller in Fig. 4 is

$$\Delta u = -K_u \Delta V_m + K_w \Delta w \tag{7}$$

where, K_u and K_w are the transfer functions in the voltage and speed loops respectively. A comparative study of various PID controllers for both K_u and K_w were carried out.

III. Simulation Results

The power system model given in Fig. 4 was simulated to test the STATCOM controller. The effect of both K_w and K_u on the dynamic performance was evaluated. Various combinations of proportional, integral and derivative (PID) controls were tried in both the speed and voltage loops. System data is given in the appendix. 100% input torque pulse for 0.05 sec. was applied to simulate a disturbance.

Figs. 5 and 6 show the generator speed and mid-bus voltage variations with control only in the speed (K_w) loop. The voltage loop has been disabled. The response with no control is shown by curve ‘a’ in both the plots.

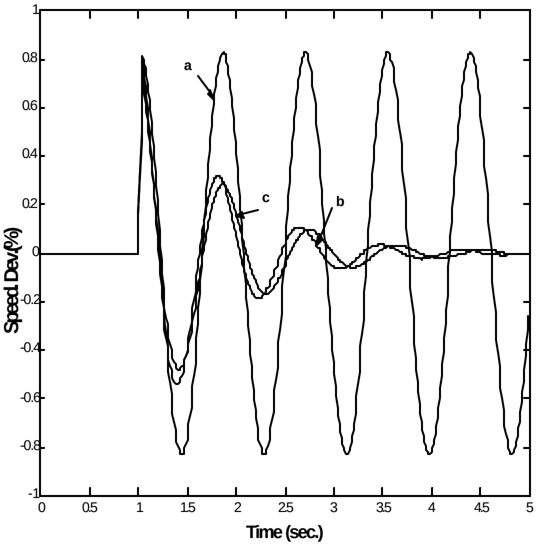

Fig. 5. %Speed Deviation (Speed loop only). (a) Without controller, (b) Proportional controller (c) PD controller

The responses with proportional and proportional-derivative (PD) controllers are shown by curves b and c, respectively. PD control is slightly superior to the proportional only. Gain of 100 has been used in Figs. 5 and 6. PI controller gives a response very close to b and is not shown. Large gains in PD controls give a spike in Voltage and controller current outputs as shown in curve c of Fig.6.

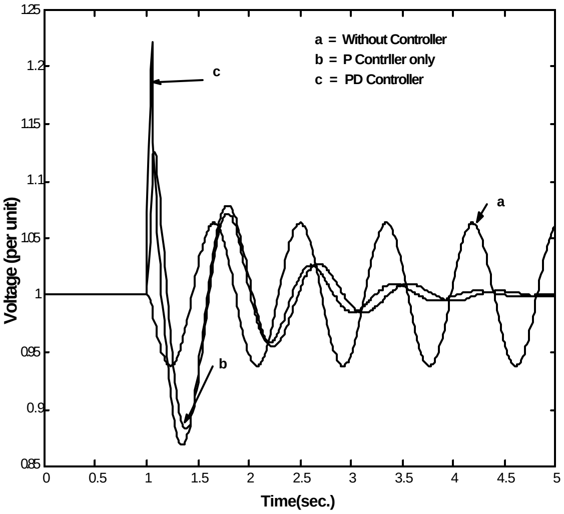

Fig. 6. STATCOM bus voltage.

Fig. 7-9 show the mid-bus voltage, generator speed and controller output current variations with control in the voltage loop K_u. The speed loop has been disabled.

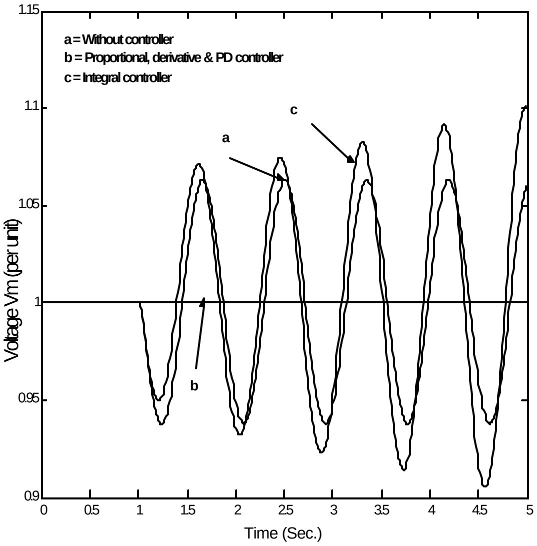

Fig. 7. STATCOM bus voltage with controller in the voltage loop.

Fig. 7 shows the variation of mid-bus voltage V_m with the various controllers. Curve a is with no control. Proportional, derivative, and PD control give almost flat voltage profile shown by curve b. This is for a gain of 10,000 in all the circuits. For lower gains, there is a very small amount of oscillation in the magnitudes. The integral or PI controls are ineffective; lager gain in these circuits gives growing voltage as shown by curve c.

Fig. 8 shows the variation of generator speed with the various controllers tested. The no control response, which is completely oscillatory, has not been shown. The derivative controller (or lead compensator) does provide some damping, but is insignificant as shown by curve c. The proportional control, or the PD control shown by curves a and d are also not effective. The PI control (curve b) give growing response. Similar characteristics are observed in the controller current output shown in Fig. 9. From analysis of Fig. 7-9 it is apparent that the voltage loop provides very little damping. However, the circuit must be tuned for a reasonable gain to give proper voltage regulation.

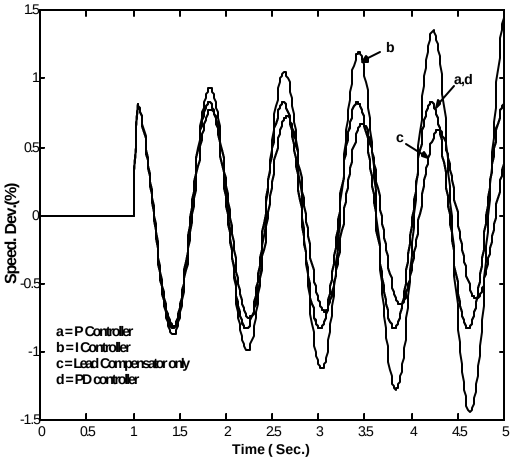

Fig. 8 Percent speed deviation with controllers in the voltage loop.

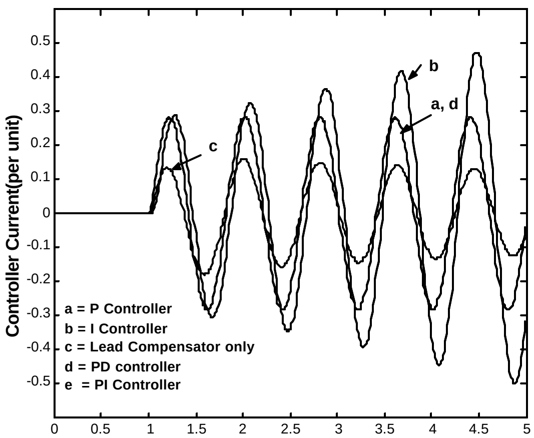

Fig. 9. Controller current output with controllers in the voltage loop.

The power system model is then tested by applying control in both speed and voltage loops. As has been observed, no control other than proportional is suitable in the voltage loop. Figs. 10, 11 and 12 show the mid-bus voltage, controller current output and the generator rotor angle variation when both the voltage and speed loops are present. A gain of 10 has been employed in the voltage loop in the test cases shown. In Fig. 10, curve a shows the response without any control, b is with proportional control and c with PD control in the speed loop. The gains in both the proportional and derivative circuits are 100 each. If the gains are increased the damping characteristics improve but there is an overshoot initially both in the voltage response and controller current output. PI controls leads to unstable response.

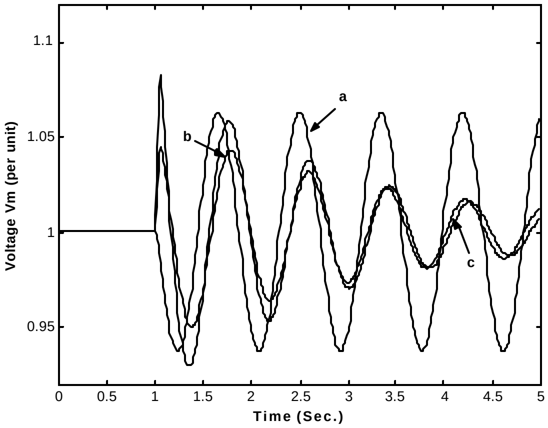

Fig. 10. STATCOM Bus voltage with proportional control in the speed loop plus, b) proportional control in speed loop, c) PD control in speed loop. 'a' is with no control.

Fig .11 shows the variation of the controller current output. The PD control in the speed loop is seen perform better than other controllers. Fig. 12 shows the rotor angle variation of the generator with controls in both speed and voltage loops. PD controller (or a lead compensator) in the speed loop with a proportional voltage controller provides better damping characteristics.

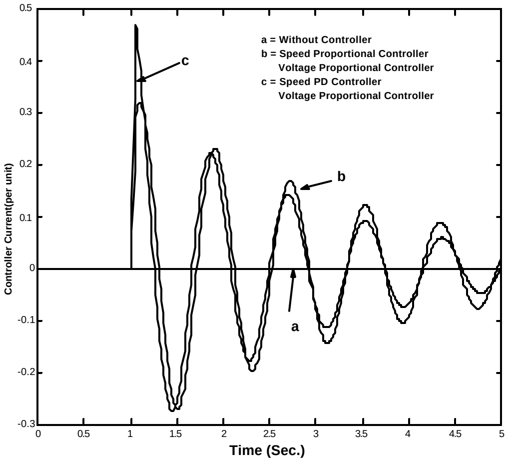

Fig. 11 Controller output current with control in voltage as well as speed loop. Symbols are as in Fig.10.

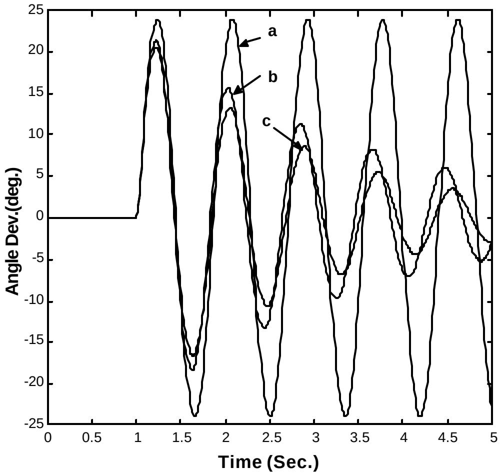

Fig. 12 Generator rotor angle deviation with controllers in both voltage and speed loops. Symbols are as in Fig.10.

IV. Conclusions

Dynamic performance of a single machine infinite bus power system with SATCOM installed at its mid-pint has been investigated. A Comparative study has been carried out with controllers installed in speed control loop, voltage control loop and a combined speed-voltage control loop. Proportional, derivative and integral controllers and their combinations were simulated. It has been observed that the controller speed loop can be tuned to provide damping to the electrical as well as electromechanical transients. The voltage loop alone, however, does not provide significant damping to the system. The presence of the voltage loop is a must for effective voltage control. A PD controller in the speed loop in addition to the normal proportional control in the voltage loop provides the best damping properties compared to other PID controllers.

V. References

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Appendix: System Parameters

Generator: $x_d' = 0.3$, $x_q=0.6$, $x_d=1$; D=0; H=3.0
Transformer: $x_{T1}=x_{T2}=0.1$
Transmission line: $x_{L1} = x_{L2} = 0.2$
STATCOM: $I_{smax} =0.5$, $I_{min} =-0.5$, $I_{so}=0$, T=0.02s, K=1.0

Operating values: $P_{eo}=0.9$, $V_b=1.0$, pf = 0.991

Bibliography

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